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High Penetration of Wind Energy into Island Diesel Grids Experience from Cape Verde

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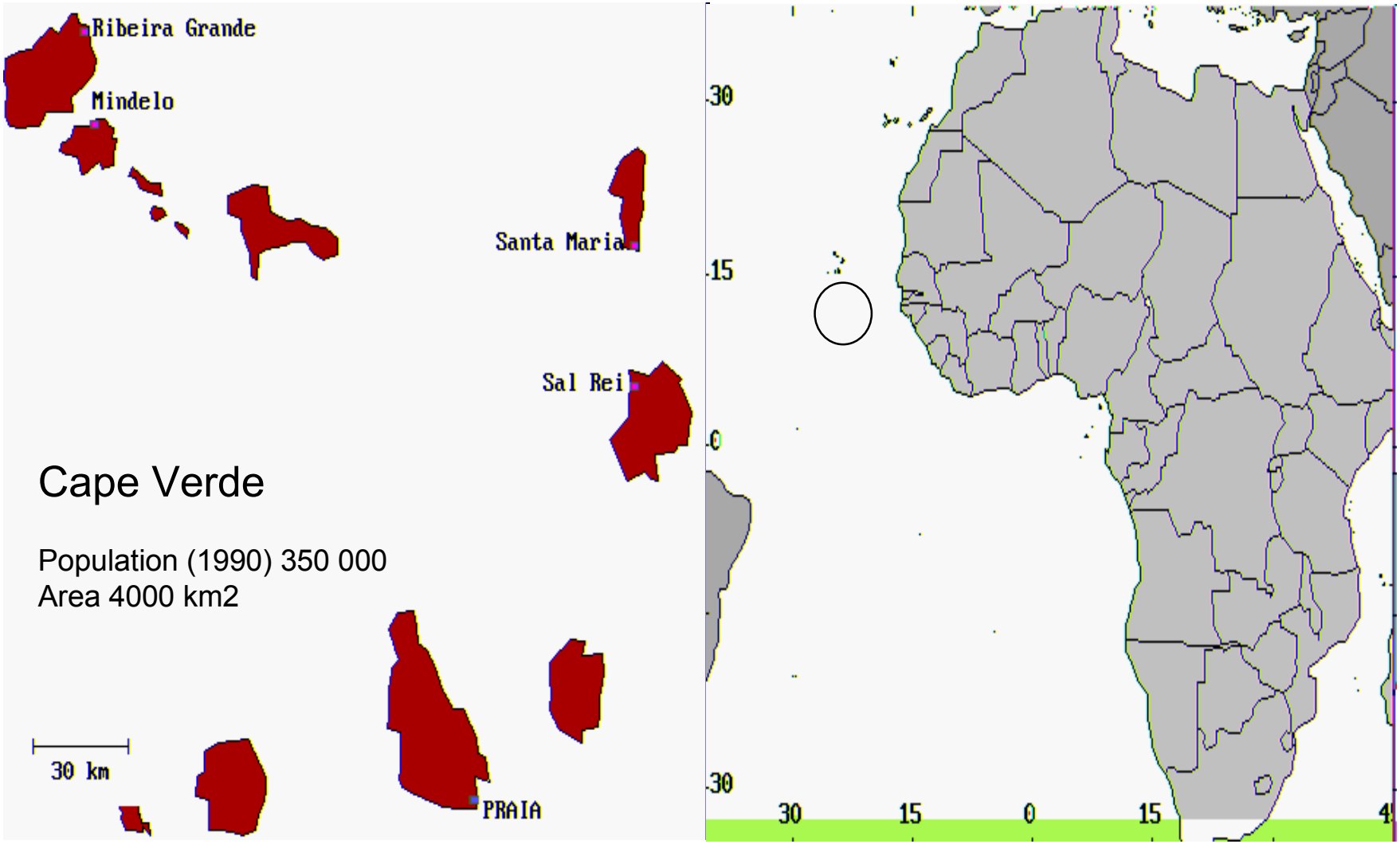
Overview of the presentation

- *Introduction*
- *Overview of Wind Energy in Cape Verde*
- *Brief power system description*
- *Step 1 Wind Farm - experience and power system performance*
- *Step 2 Feasibility & initiation of further expansion*
- *Conclusions and recommendations*

Cape Verde


Ribeira Grande
Mindelo
Santa Maria
Sal Rei
Cape Verde
Population (1990) 350 000
Area 4000 km2
30 km
PRAIA
30
15
0
30
30
15
0
15


0 40 80 km
0 40 80 mi
Santo Antão
Mindelo
Santa Luzia
São Vicente
Ilhas do Barlavento
São Nicolau
Sal
Santa Maria
North Atlantic Ocean
Boa Vista
Ilhas do Sotavento
Tarrafal
Maio
Brava
Fogo
São Tiago
PRAIA

Cape Verde

Wind Energy in Cape Verde

Wind power was used to pump sea water into basins to evaporate in the sun, leaving the salt to be traded

The old water pumpers were made by wood, some say driftwood.

One of the old water pumpers are now on display in the island Sal

Wind Energy in Cape Verde I

Republic of Cape Verde

Based on information from ELECTRA

Location	Installation	Implementor	Donor/Investor	Working
Ponta d'Agua - Praia	2x55 kW Vestas - grid	INIT	UNSO/Danida	No
Assomada - Santiago	1x55kW Bonus - W/D	INIT	UNSO/Danida	No
Tarrafal - Santia	1x30 kW Lagerwey W/D	MDR	Holland	No
Mt. R. Juliao - Mindelo	10x30 kW Aeroman - grid	ELECTRA	Germany/KfW	20%
Santa Maria - Sal	1x75 kW Vestas - W/D	Morabeza Hotel	Morabeza Hotel	Yes
Palmeira - Sal	*2x300 kW NTK - W farm*	*ELECTRA*	*Danida/Cape Verde*	*Yes*
Mt. Montona - Mindelo	*3x300 kW NTK - W farm*	*ELECTRA*	*Danida/Cape Verde*	*Yes *)*
Mt. S. Felipe - Praia	*3x300 kW NTK - W farm*	*ELECTRA*	*Danida/Cape Verde*	*Yes*
Brava	1x150 NTK - W/D	Municipality	Germany/GTZ/Danida	Yes
Boa Vista	5x15 kW Vergnet - W farm	Municipality	France	Yes **)
Matão - Santiago	1x15 kW Vergnet - W/B	INERG	France	Yes

**) One temporarily down with gearbox problems; **) Performace to be enhanced by improved rotor*

Island systems energy penetration 14%, power penetration 35% without problems

Wind Energy in Cape Verde II

- **Small systems**
  - Several systems of prototype nature
  - Several not successful due to lack of skill of maintenance staff and immature technology
  - At least one successful: SR&R system, skilled operator, commercial system
  - Still activity in the area with new installations
- **Larger systems**
  - High penetration systems (14% annual energy coverage)
  - Grid connected wind turbines on diesel grids
  - No extra equipment
  - Satisfactory operating experience
  - Satisfactory power quality
  - In the process of increasing the installed capacity and the penetration level

Wind energy resources

annual average wind speeds and Weibull parameters at 30 m height

	U_{mean} (m/s)	Weibull - A (m/s)	Weibull - k
Praia - Mt. S. Filipe	7.8	8.9	3.62
Mindelo - Selada Flamengo	10.4	11.7	4.02
Sal - Palmeira	7.4	8.3	3.62

There IS wind in Cape Verde

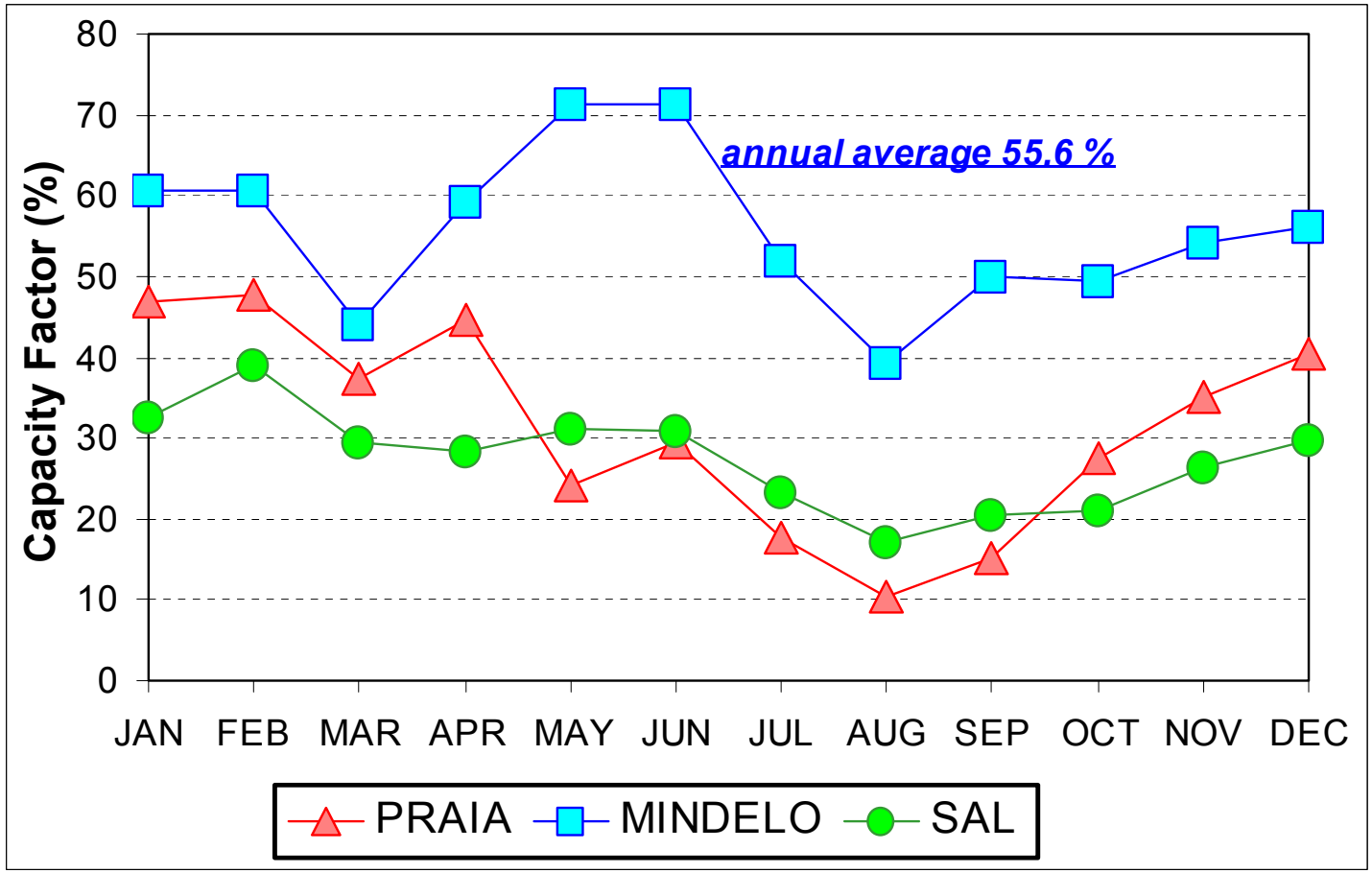
Key figures for Cape Verde (step 1)

Operation statistics for Step 1 Wind Farms averages 1995 - 1997

	Sal	Mindelo	Praia
Available diesel capacity (MW)	4	11	12
Diesel fuel type	gas oil	heavy fuel	gas oil
Installed wind turb. capacity (kW)	600	900	900
Avg. wind speed at hubheight (m/s)	7.4	10.4	7.8
Annual wind energy production (MWh)	1440	4390	2500
Annual power system load (MWh)	10120	32800	39870
Avg. wind energy penetration (%)	14	14	6.3
Avg. wind turb. capacity factor (%)	27	56	31
Annual diesel fuel savings (t)	340	970	615

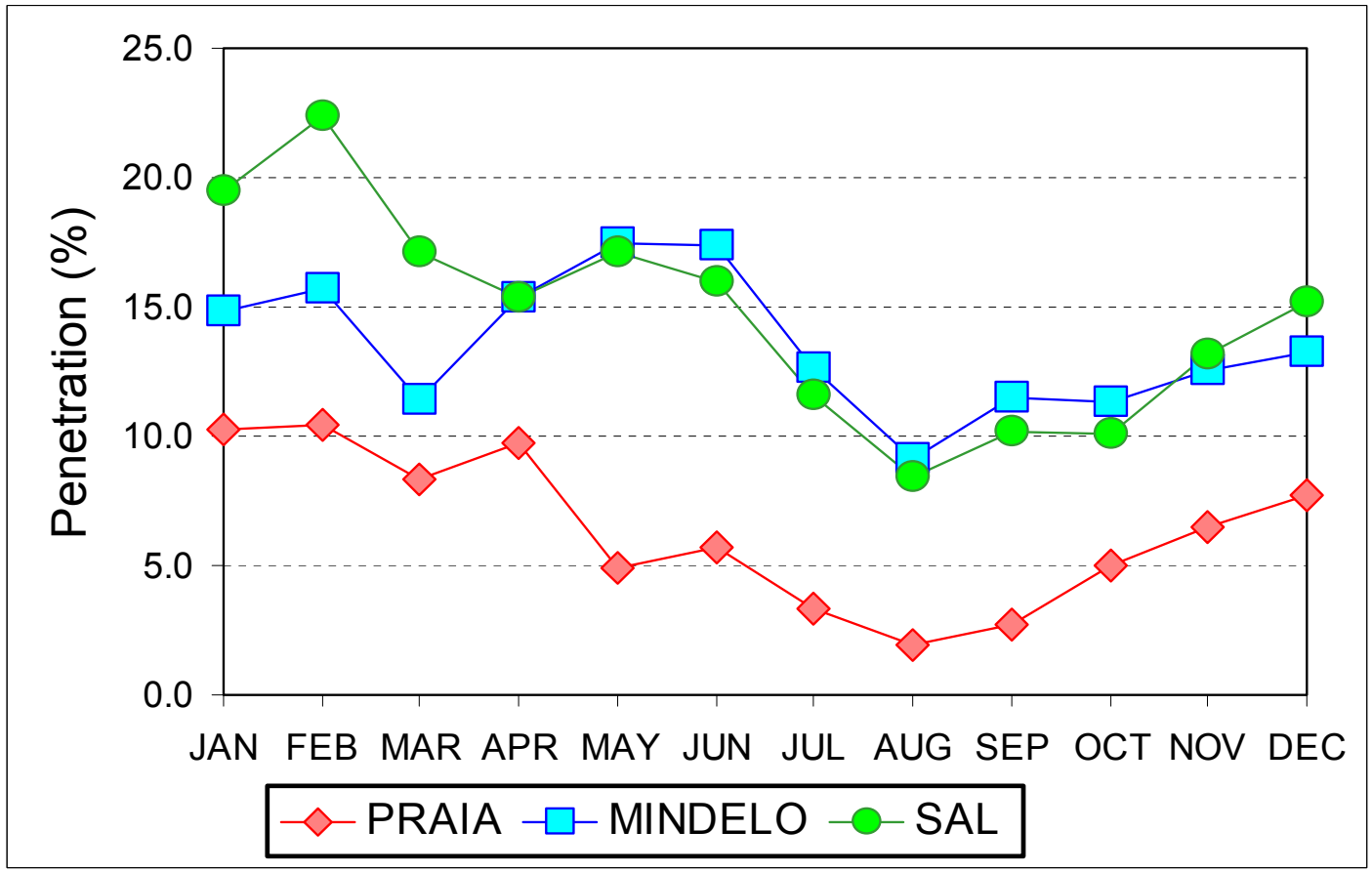
Average monthly capacity factor

Step 1 wind farms - 1995, 96 & 97



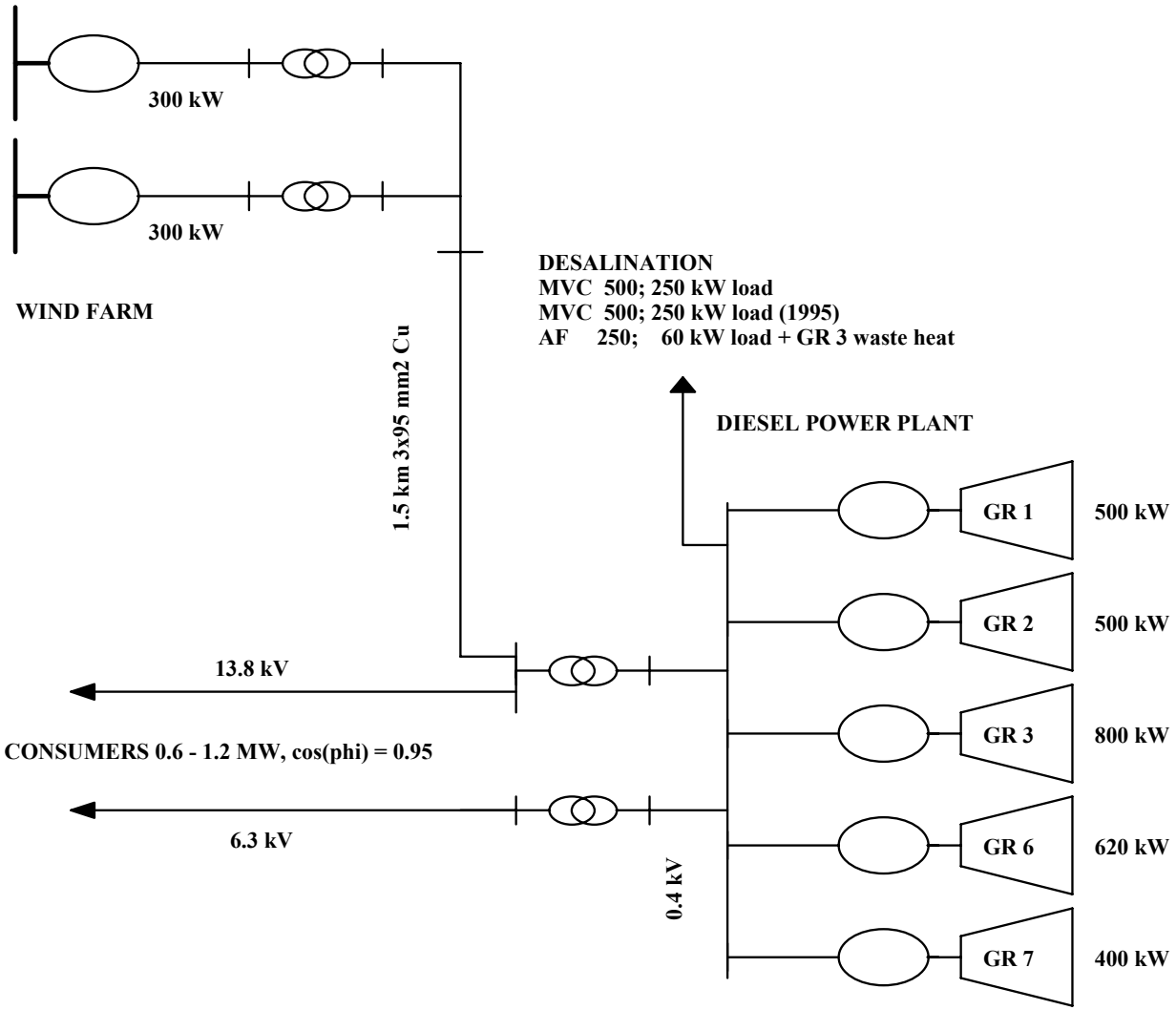
Average monthly wind energy penetration

Step 1 wind farms - 1995, 96 & 97

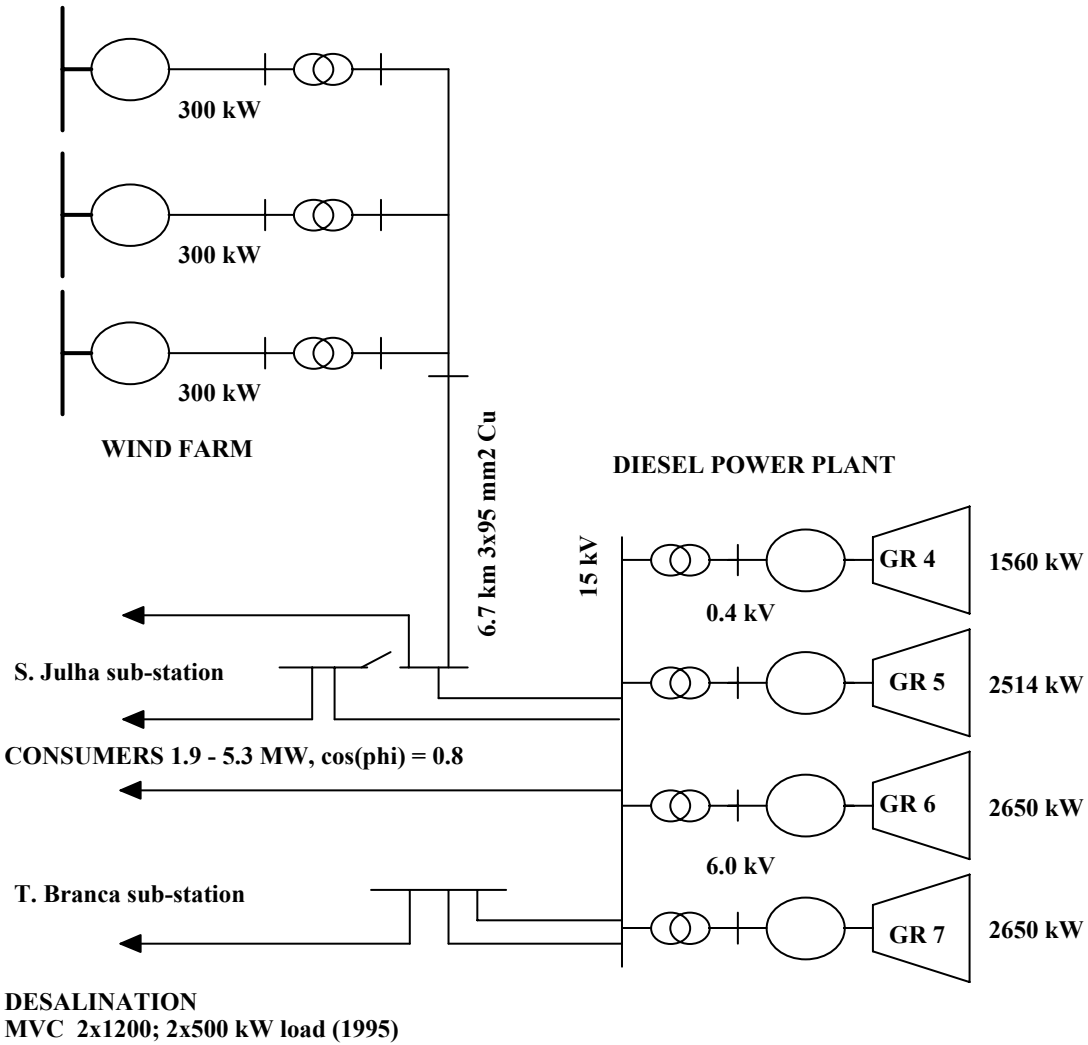


Wind turbines at Mindelo

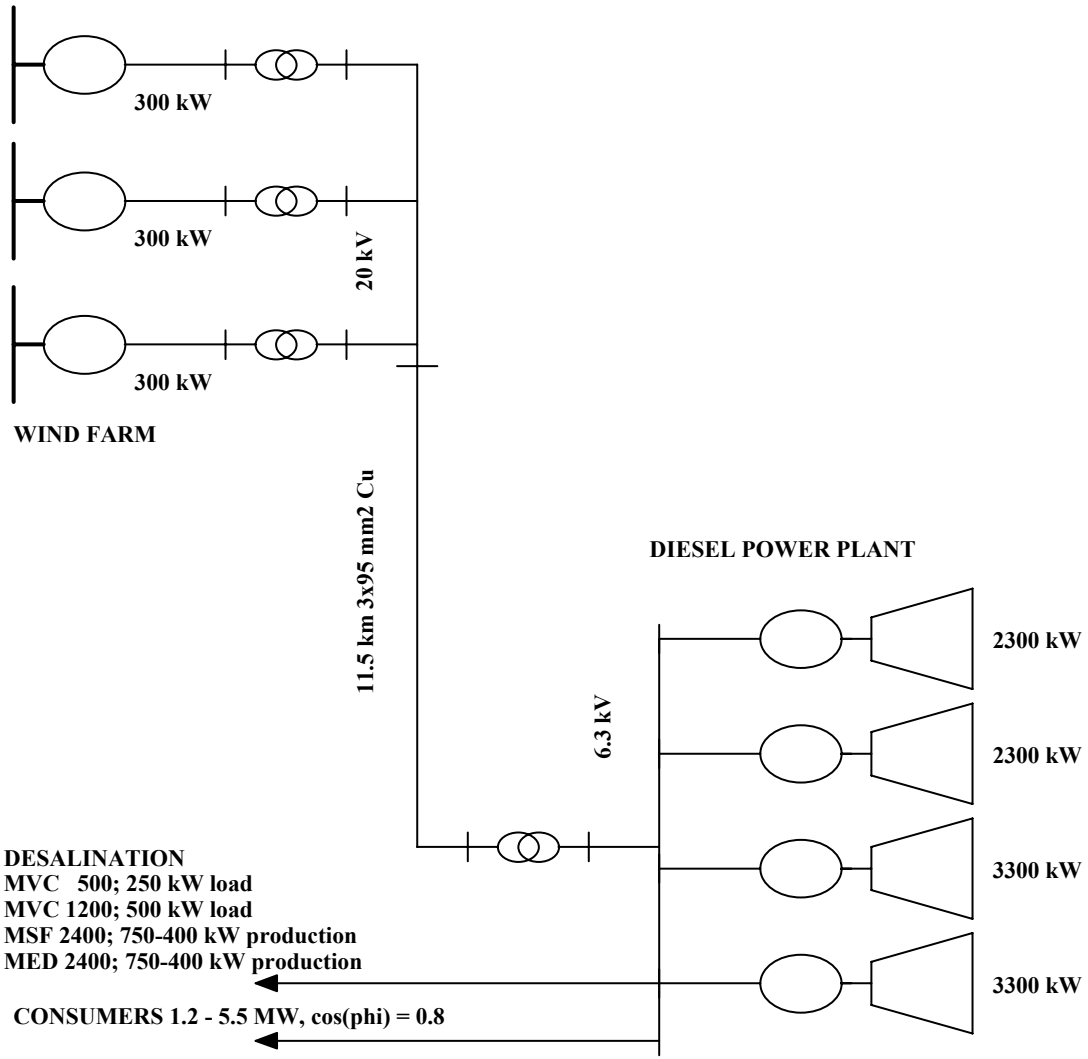
SAL POWER SYSTEM



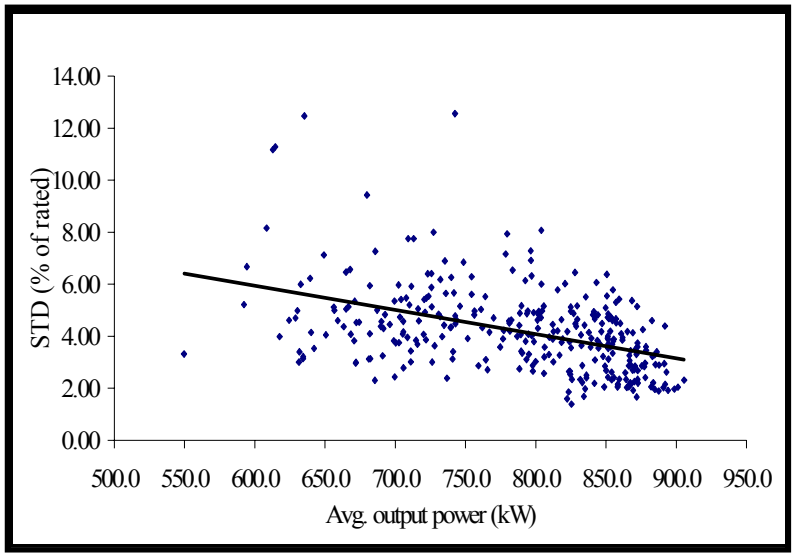
PRAIA POWER SYSTEM



MINDELO POWER SYSTEM



Power quality - fluctuations in wind power



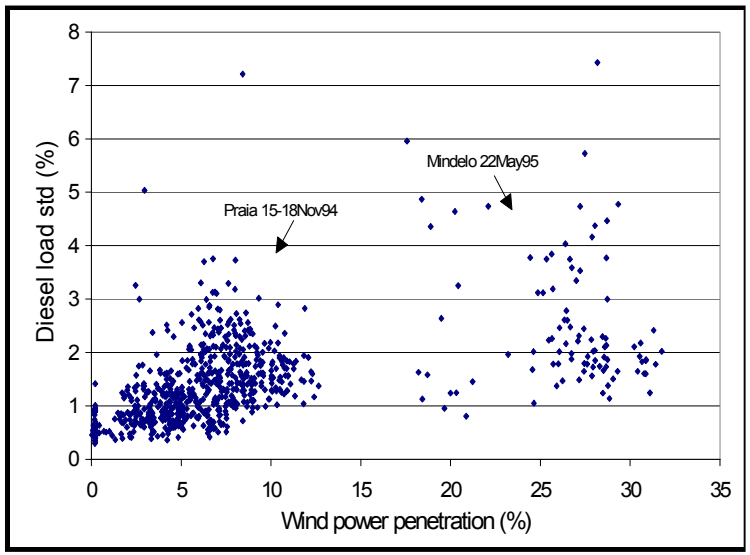
Possible impact of wind power fluctuations:

- level and fluctuations of voltage and frequency
- controllers of systems to prevent instability
- shape of the voltage
- distortion of voltage
- fluctuations of diesel generator power

Keep power fluctuations small

Fluctuation levels decrease with increasing number of wind turbines and increasing power output

Power quality - fluctuations in diesel load



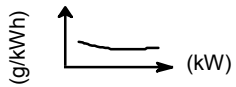
Diesel power output fluctuations typically increase with increasing wind energy penetration

Example - standard deviation below 10% of rated power for diesels:

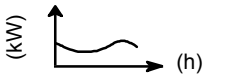
- **no increased tear or wear**
- **no increased specific fuel consumption**

WINSYS modellering

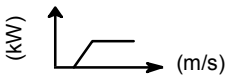
Plant specifications



Load pattern

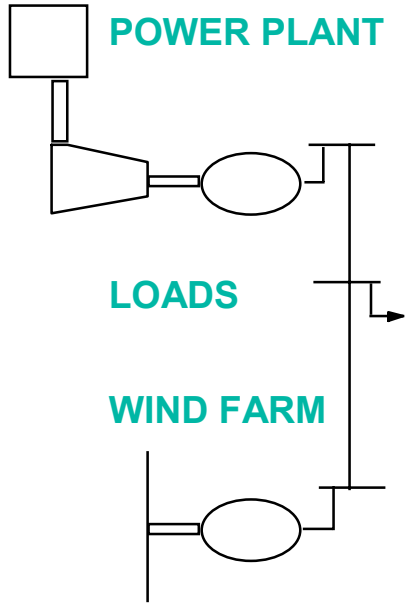


Power curve

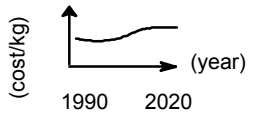


Wind speed distribution

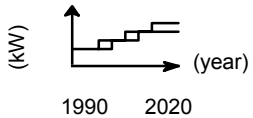
Seasonal and diurnal variations



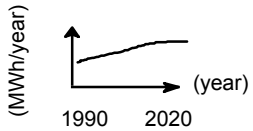
Fuel cost



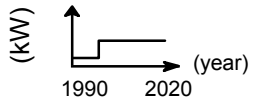
Plant development



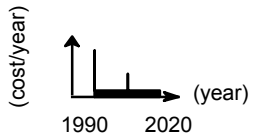
Consumer loads



Wind power capacity

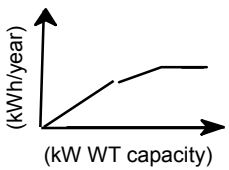


WT investment and O&M

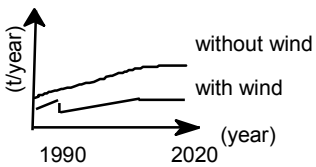


Load dispatching **WINSYS** **Unit commitment**

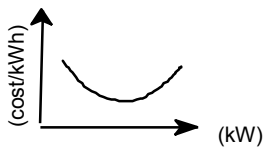
Wind energy output



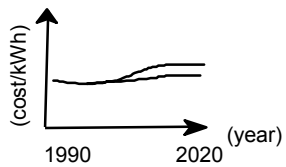
Fuel consumption



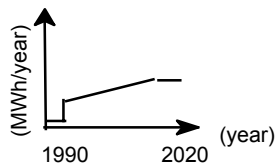
Optimum WT capacity



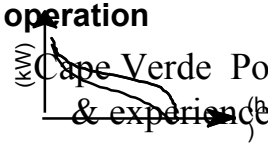
Cost of energy



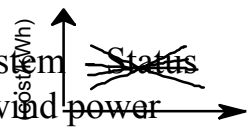
Utilized wind energy



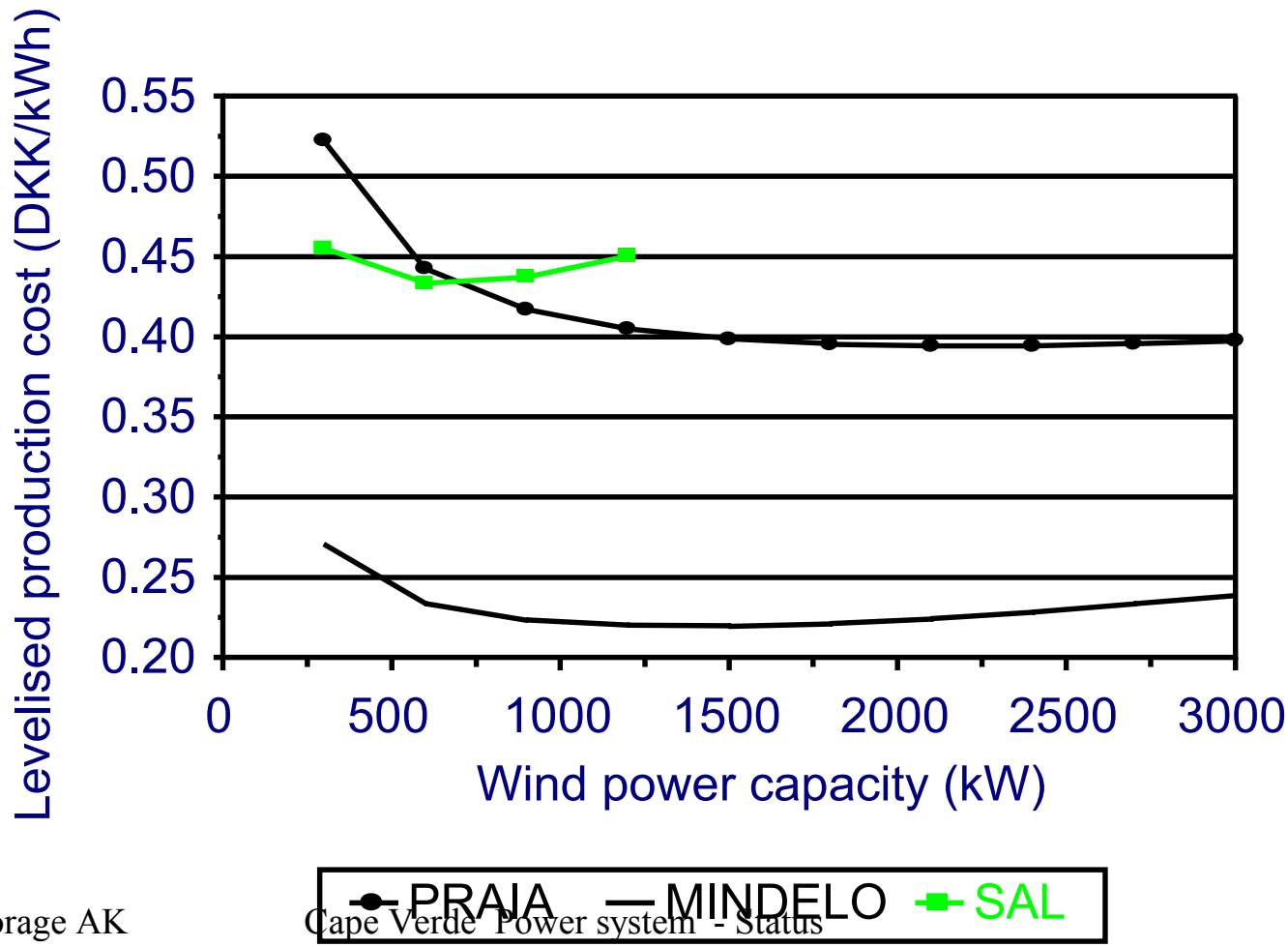
System operation



Sensitivity analysis



Cost of energy vs. wind farm size



Validation of modelling

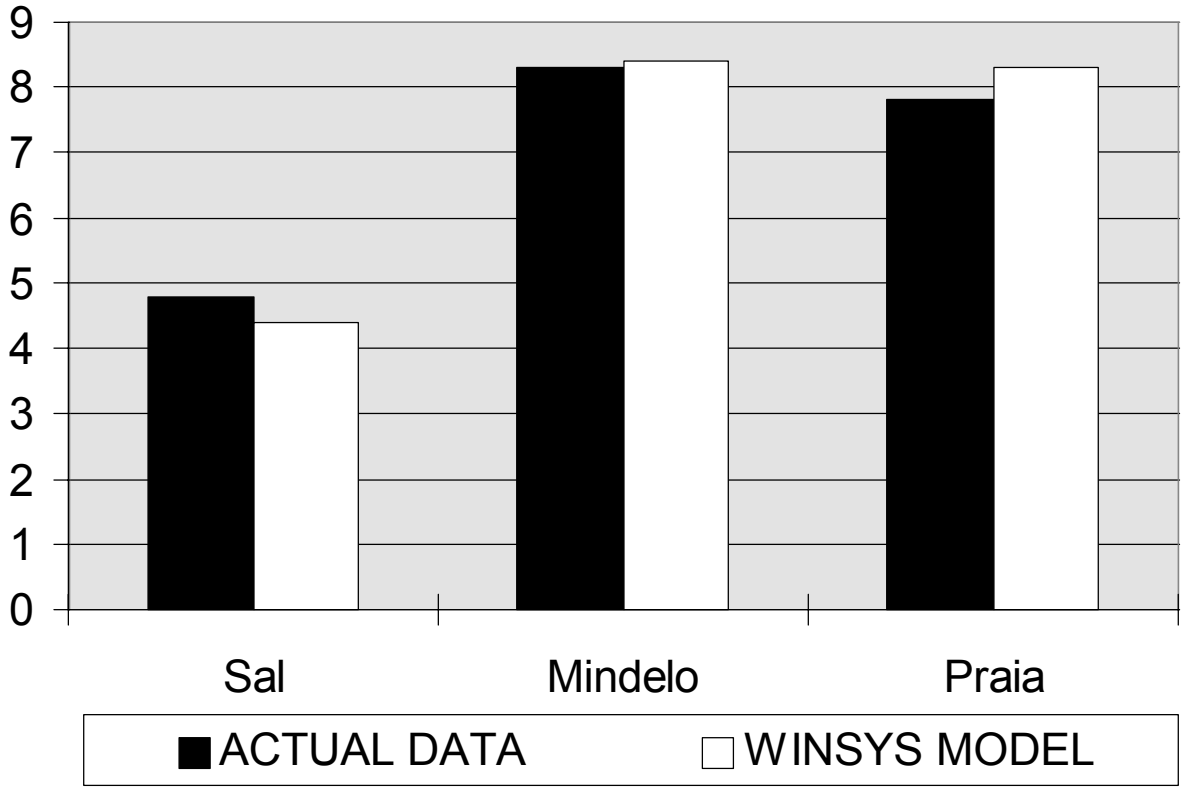


Figure 6 Comparison of actual fuel savings and result obtained by WINSYS modeling

Key figures for Cape Verde (step 2)

Feasibility study 1996, implementation decided 2000, project started 2002

		Sal	Mindelo	Praia
Existing Step 1 Wind Farm capacity (kW)		600	900	900
Recommended Wind Farm expansion (kW)		600	1200	1800
Production data for first year after installation (1997)	Step 2 util. output (MWh/year)	1366	4723	4146
	Step 2 fuel savings (t/year)	288	1098	968
	Step 1+2 total util. output (MWh/year)	2835	9303	6585
	Step 1+2 fuel savings (t/year)	598	2151	1542
	wind energy penetration (%)	24	30	18
Levelised pro-duction data for the 20 years lifetime (1997-2016)	Step 2 util. output (MWh/year)	1446	5863	4777
	Step 2 fuel savings (t/year)	306	1331	1046
	Step 1+2 total util. output (MWh/year)	2915	10473	7217
	Step 1+2 fuel savings (t/year)	617	2378	1581
	wind energy penetration (%)	16	19	7.5

Power system operation with Step 2 Wind Farms

	Praia	Mindelo	Sal
Step 2 wind farm capacity (kW)	1800	1200	600
Potential energy output (MWh/y)	5350	6744	1578
Annual utilized energy (MWh/y)	4777	5863	1446
Wind farm investment (USD/kW)	892	892	892
Other investments (USD/kW)	433	472	426
Total investment (USD/kW)	1325	1364	1318
O&M (% of wind farm investment)	2.5	2.5	2.5
Retrofit cost (% of wind farm invest.)	10	10	10
Salvage value (% of wind farm invest.)	0	0	0
Capacity credit (%)	24	44	18
Annual fuel savings (ton/y)	1046	1331	306
Diesel plant operation time savings (hours/y)	282	1306	82
Levelized production costs (USD/kWh)	0.062	0.034	0.066
Wind energy penetration - 1. year Step 1+2 (%)	18	30	24
Wind energy penetration - levelized Step 1+2 (%)	7.5	19	16

Economic analysis

costs and benefits discounted to present value
lifetime 20 years, discount rate 8 % p.a.

	Praia	Mindelo	Sal
Step 2 wind farm capacity (kW)	1800	1200	600
Step 2 wind farm costs (kUSD)	2855	1949	947
Annual utilized energy (MWh/y)	4777	5863	1446
Fuel savings (kUSD)	2848	2975	1030
Non fuel O&M savings (kUSD)	36.5	166	8.2
Capacity credit (kUSD)	260	327	65
Net present value (kUSD)	290	1519	156
Internal rate of return (%)	9.8	20.5	10.6
External savings (kUSD)	722	886	218
Net present value (kUSD)	1012	2405	374
Internal rate of return (%)	13.8	27.0	14.1

Wind energy impact on power system

		Sal	Mindelo	Praia
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Conclusions

Evidence has been provided from Step 1 Wind Farms

- that wind power is feasible at wind energy penetration levels at least up to 25% with
  - a record high capacity factor of 55.6% as the average for 3 wind turbines for 3 years in Mindelo
  - average penetration for 3 wind farms in 3 years is 14%
  - maximum monthly wind energy penetration of 35% in Sal Feb. 1995
- that local power company and contractors can do local works
- that capacity building can be integrated in power company organization
- that modelling of power system performance (WINSYS) is possible

Wind farm expansion is feasible

- government policy and power company motivated and ready
- economic optimum wind farm size is higher than recommended project size
  - national economy / power company finances / IRR of project / consumer price
  - internalization of the external savings due to environmental benefits improve the economics of the proposed project by 40%
  - lack of international experience makes uncertainties and risks seem high
- international need for such pilot and demonstration projects